Much Ado About Nothing

Lecture 8 May 24, 2003

Most of the universe is dark !

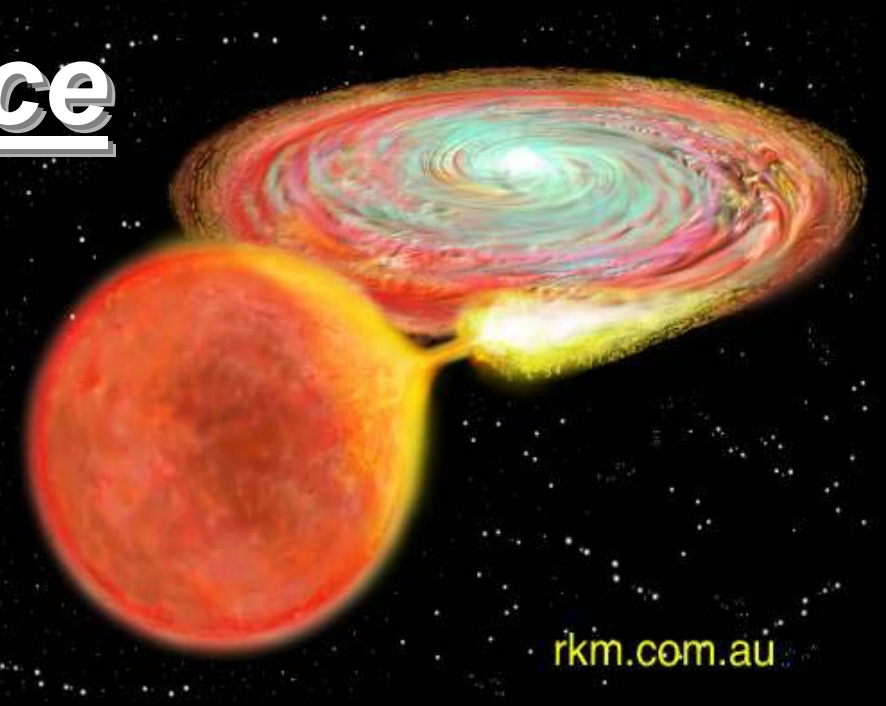
- Modified Newtonian dynamics
- Planets
- Mass & light disadvantaged stars

  brown red white
- Black holes
- Fossil remnant of the big bang
- The weight of space

The weight of space

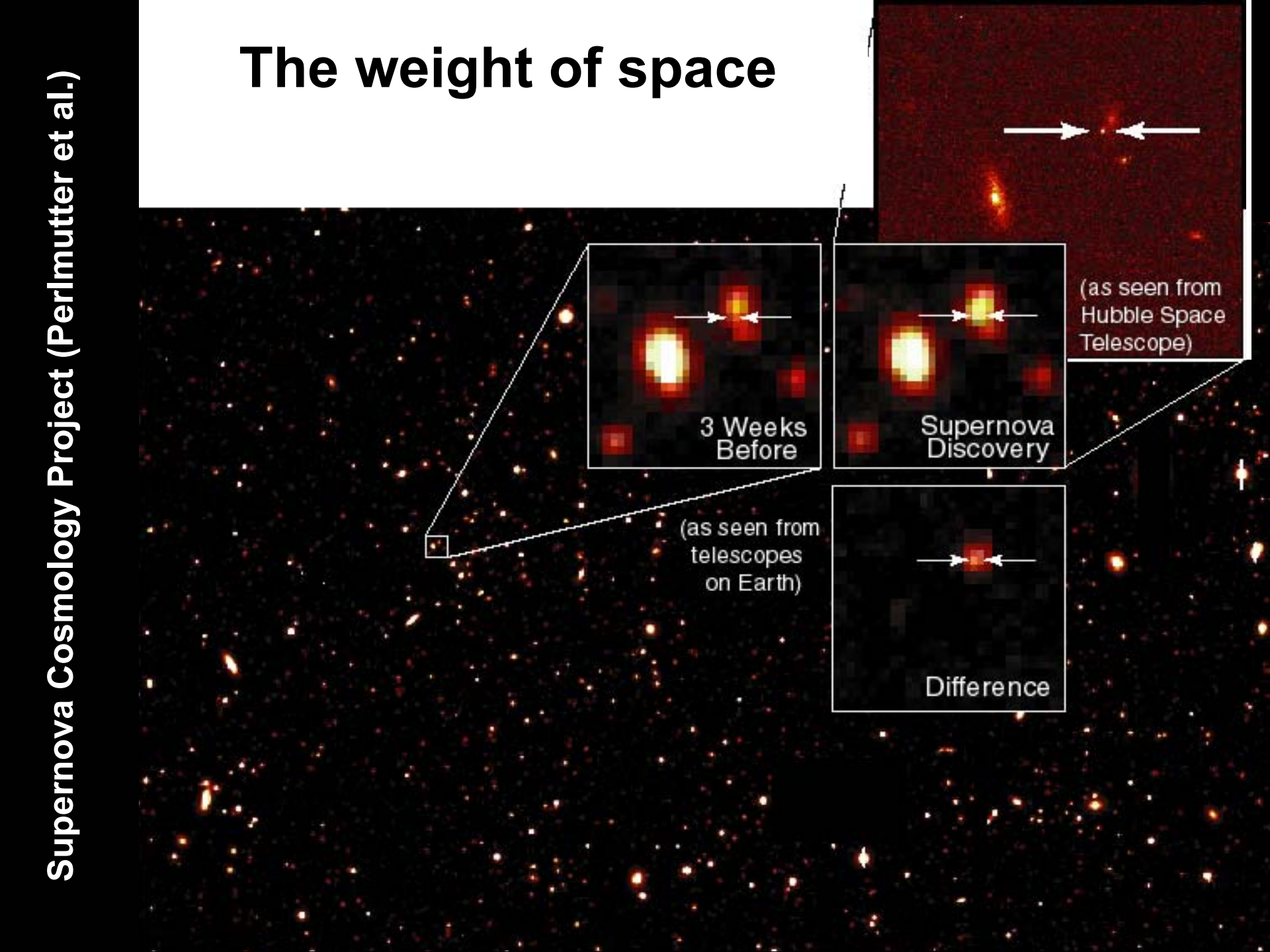
Supernovae

- Tycho
- Great Debate
- Dark Energy

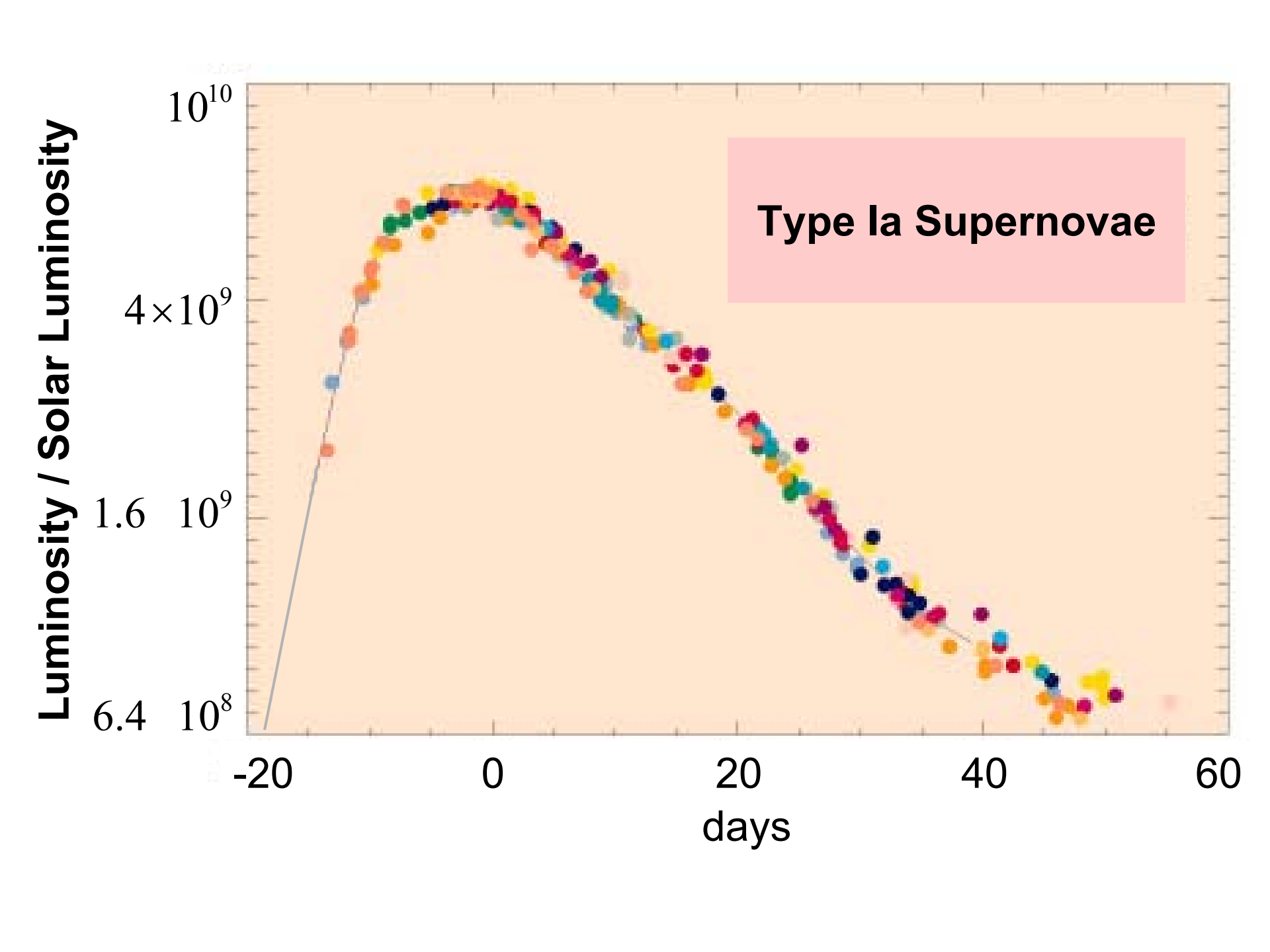


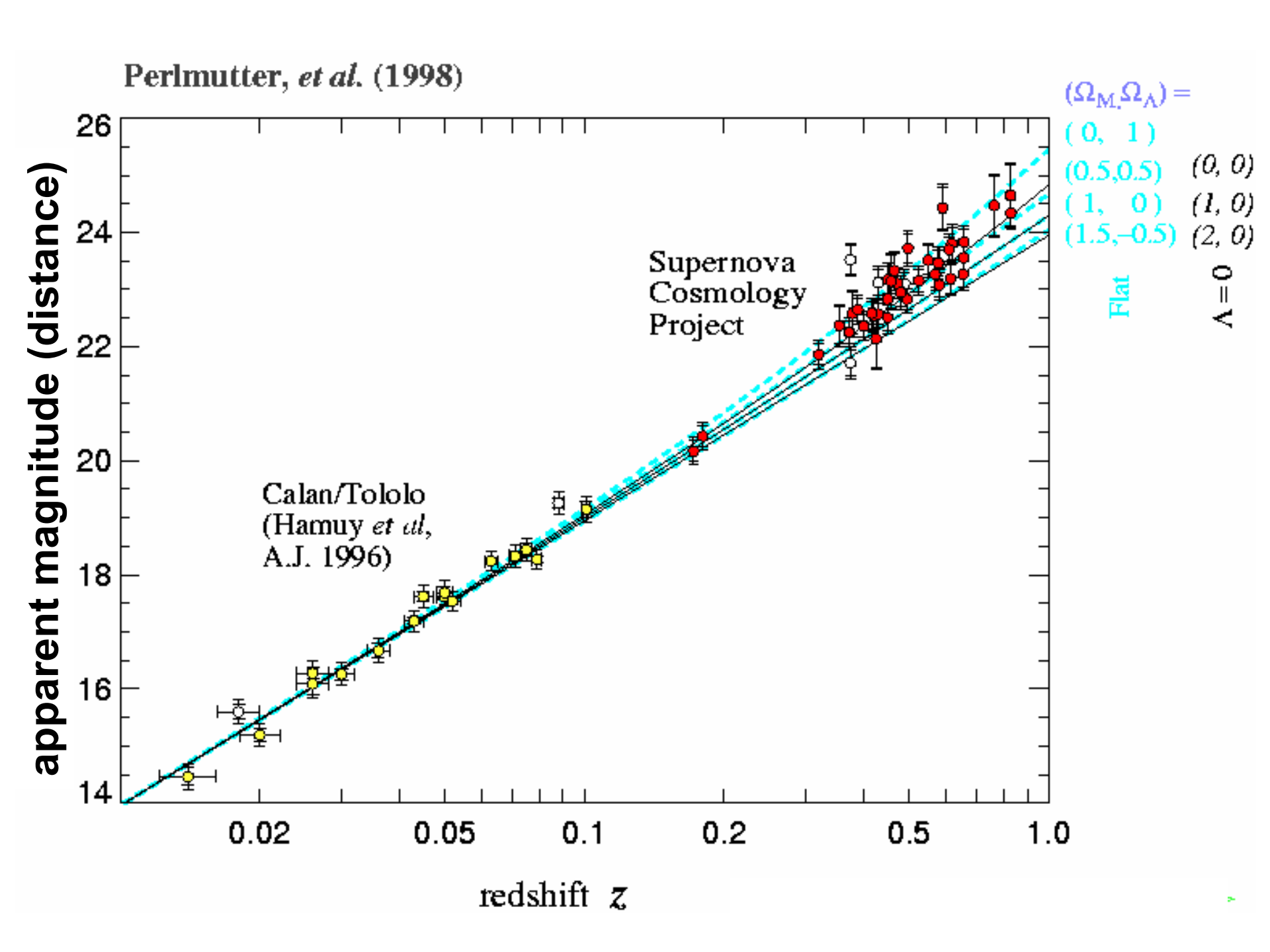
Supernova 1987A in the Large Magellanic Cloud

The weight of space

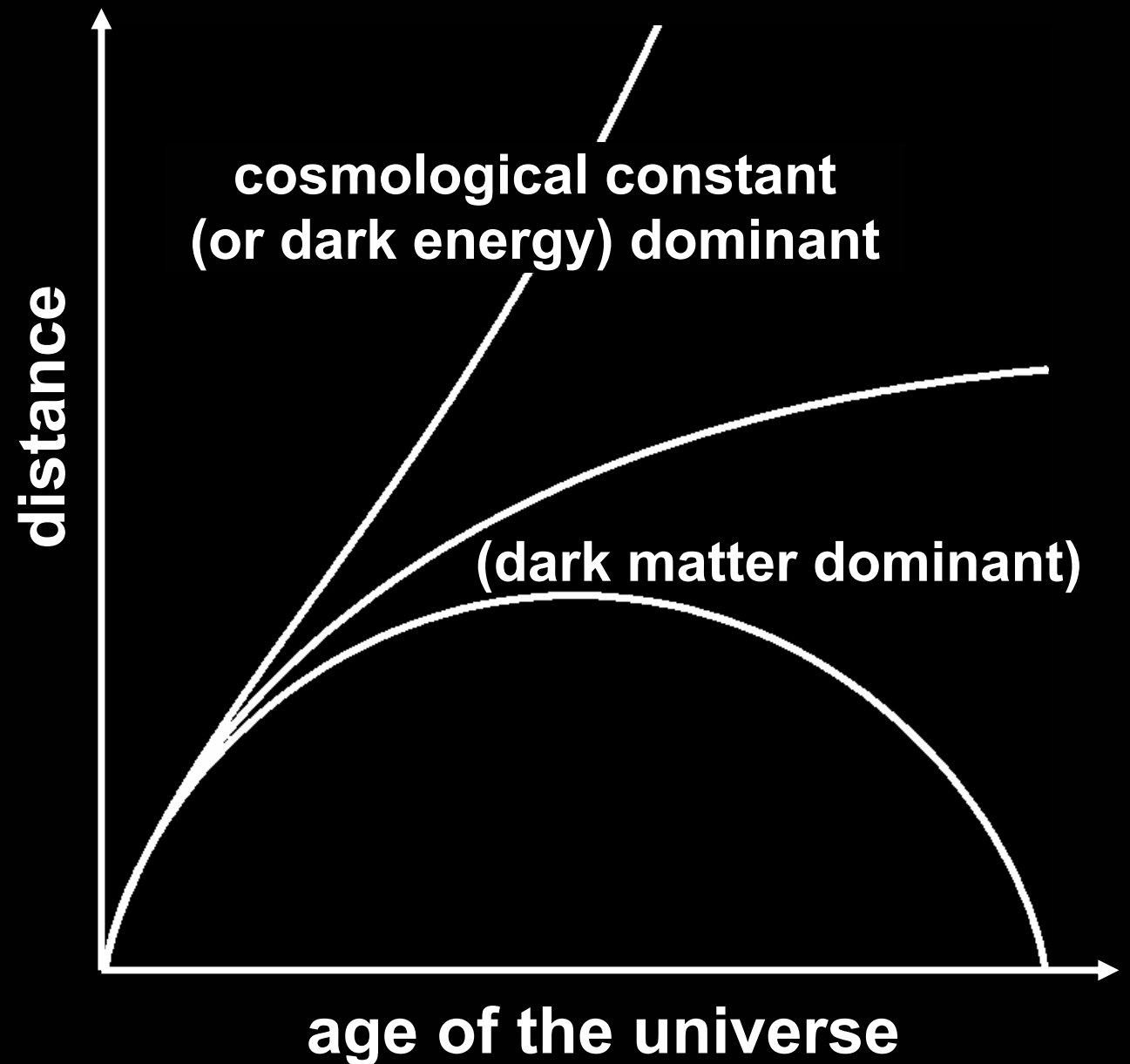


Supernova Cosmology Project (Perlmutter et al.)


Type Ia Supernovae
Luminosity / Solar Luminosity
10^{10}
4×10^{9}
1.6 10^{9}
6.4 10^{8}
-20
0
20
40
60
days


Perlmutter, et al. (1998)
apparent magnitude (distance)
26
24
22
20
18
16
14
0.02
0.05
0.1
0.2
0.5
1.0
redshift z
Supernova
Cosmology
Project
Calan/Tololo
(Hamuy et al,
A.J. 1996)
(ΩM,ΩΛ) =
(0, 1)
(0.5,0.5)
(1, 0)
(1.5,–0.5)
(0, 0)
(1, 0)
(2, 0)
Flat
Λ = 0

Cosmological constant (dark energy)



Dark energy

Space and time are related.

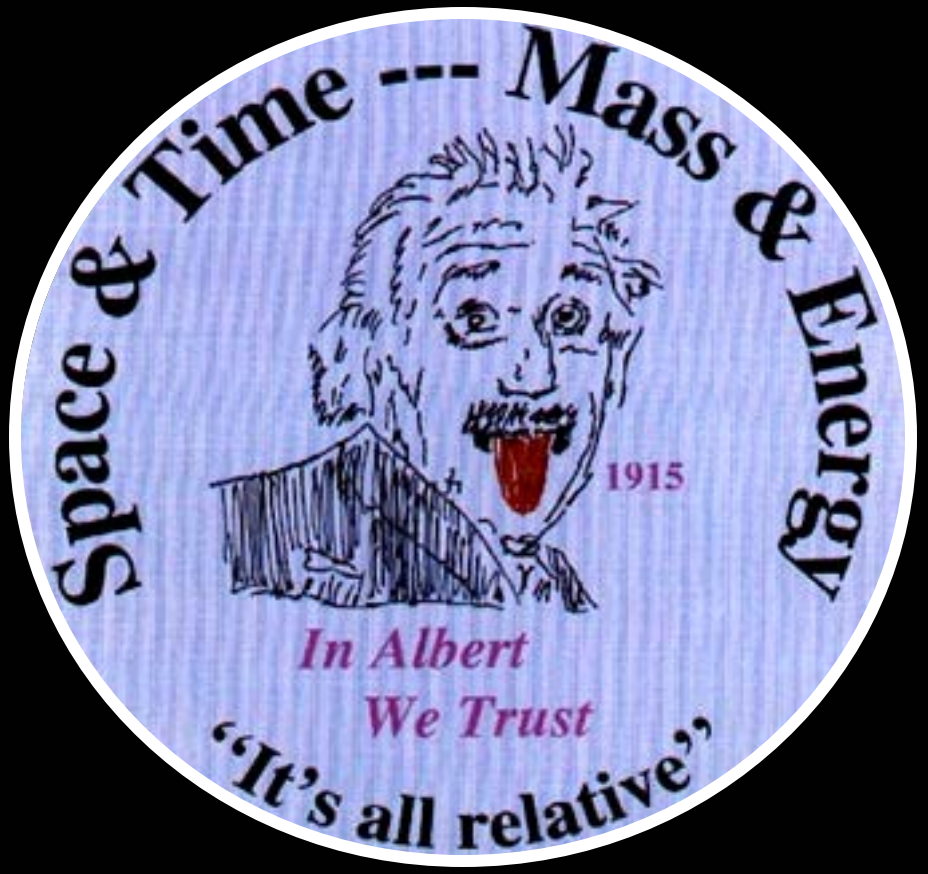
1905

Space is dynamical (curved, warped, bent).

1915

Empty space has a weight.

1917



the weight of space

Cosmological constant

(dark energy)

1917 Einstein proposed cosmological constant.

1929 Hubble discovered expansion of the universe.

1934 Einstein called it "my biggest blunder."

1998 Astronomers found evidence for it.

The accelerating universe?

Normal matter slows the expansion of the universe (deceleration). Gravity is attractive.

$$\text{acceleration} = -G \times (\text{Mass} + \text{pressure})$$

Newton — Mass

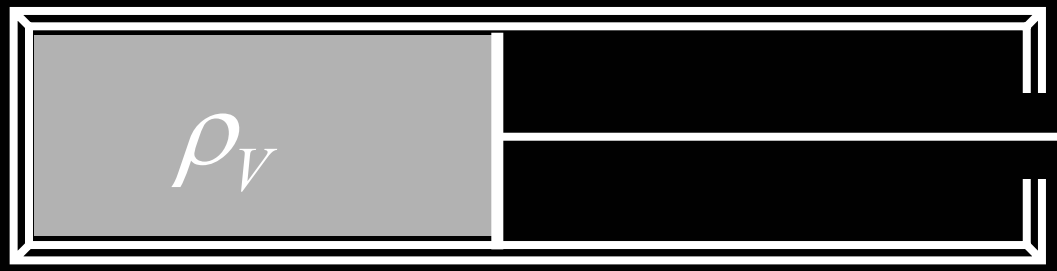
Einstein — pressure

Negative pressure would push apart space.

"Vacuum energy" (the mass-energy density of space) is positive, but its pressure is *negative.*

Vacuum pressure

$E_1 = \rho_V \times$ volume



$E_2 = \rho_V \times$ volume

$E_2 > E_1$

had to pull out piston

“negative” pressure

Cosmological constant (dark energy)

Mass density of space: $10^{-30}\ \mathrm{g\ cm^{-3}}$

The unbearable lightness of nothing!

Cosmo-illogical constant?

Much ado about nothing (the zen of nothingness)

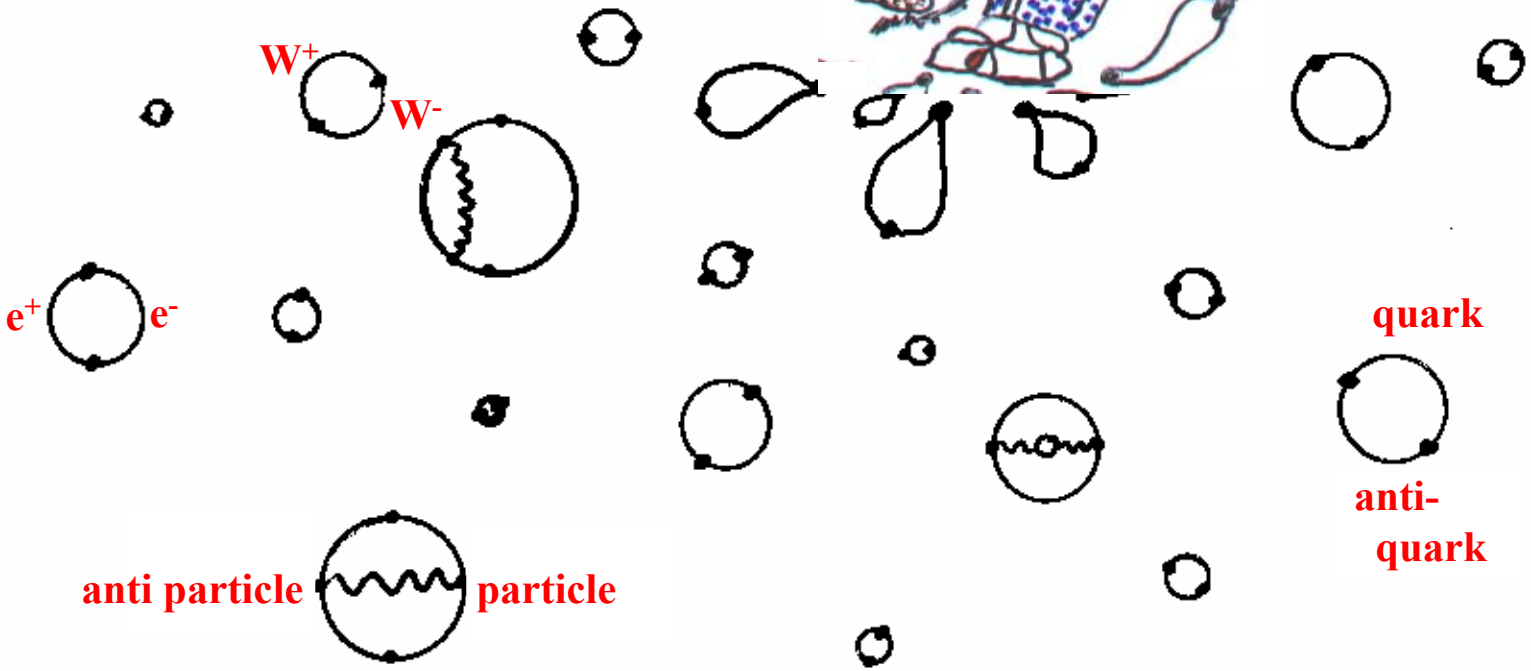
NOTHING is something!

NOTHING has energy!

NOTHING matters!

NOTHING changes!

The Vacuum of Quantum Uncertainty



Energy of the quantum vacuum

Observed: $\rho \leq 10^{-30}$ g cm^{-3}

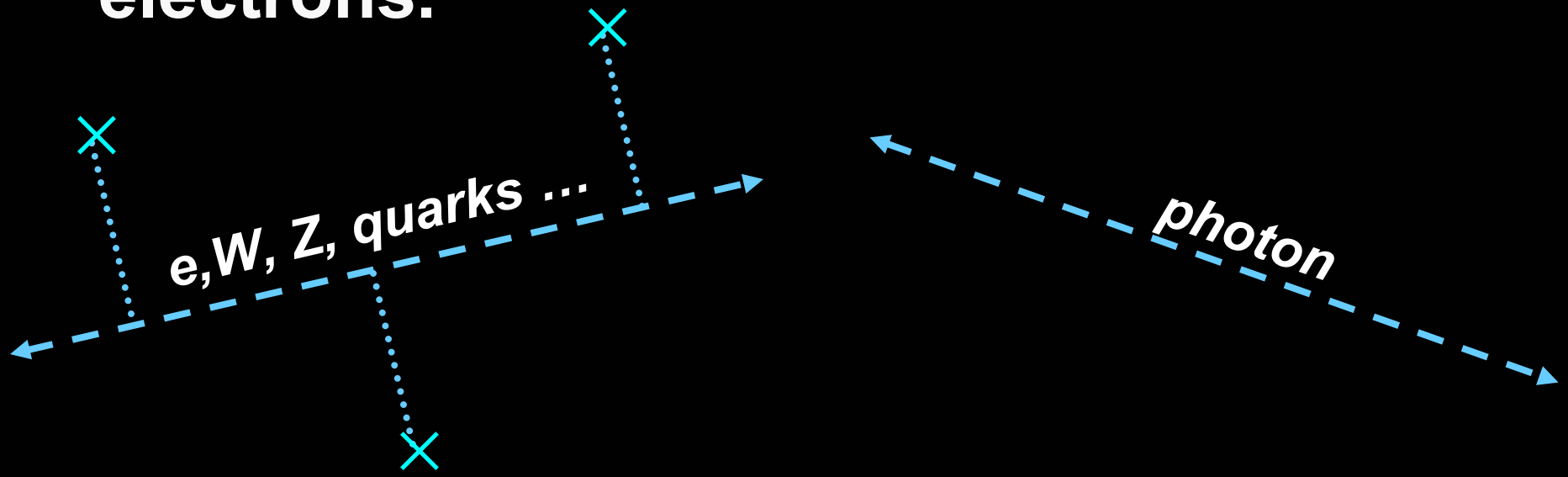
Quantum field theory: $\rho = \infty$ g cm^{-3}

Quantum gravity: $\rho = 10^{+90}$ g cm^{-3}

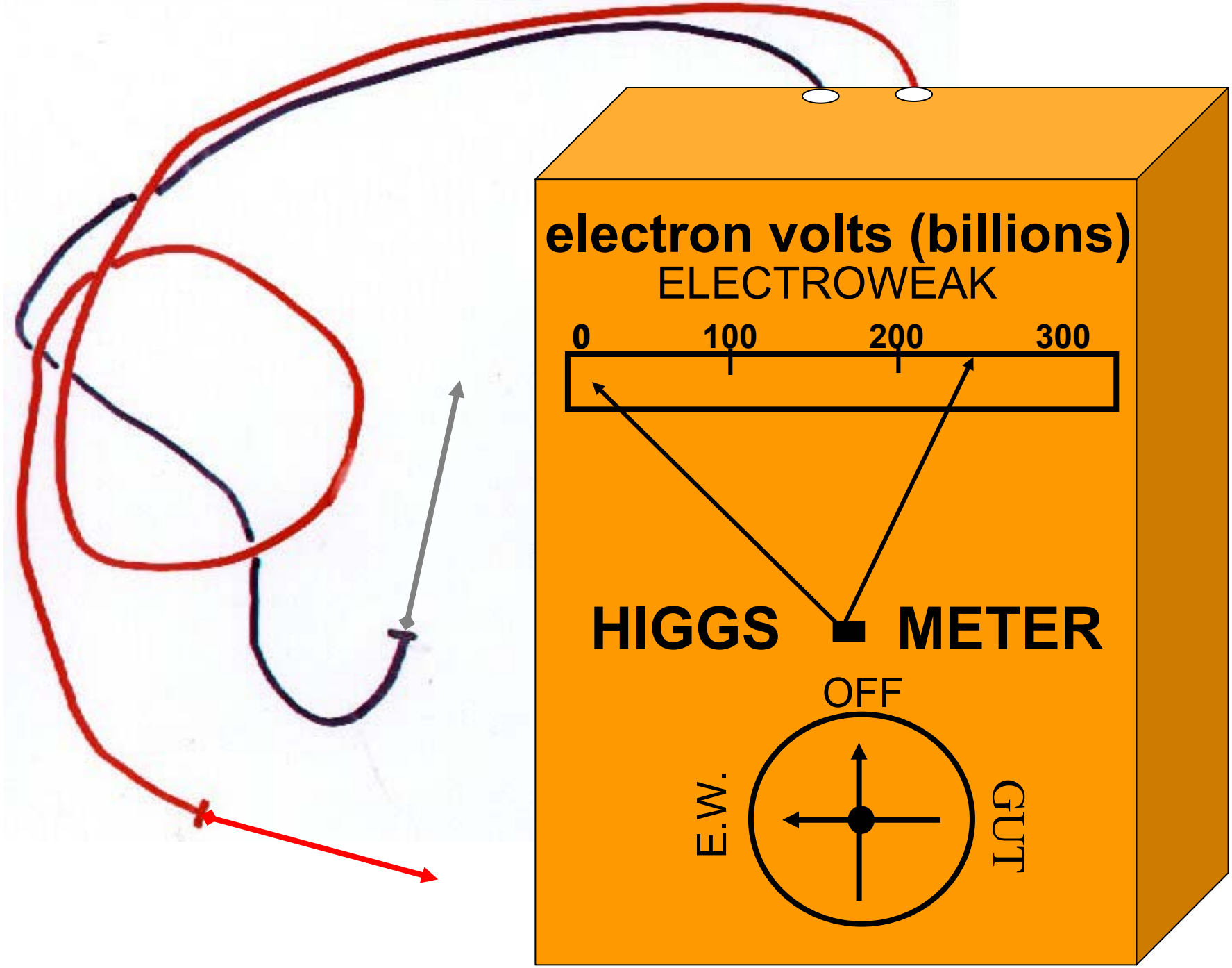
Supersymmetry: $\rho \leq 10^{+30}$ g cm^{-3}

The Higgs potential

- The vacuum has a “Higgs potential”
- Interaction with the Higgs field potential gives mass to particles like quarks and electrons.

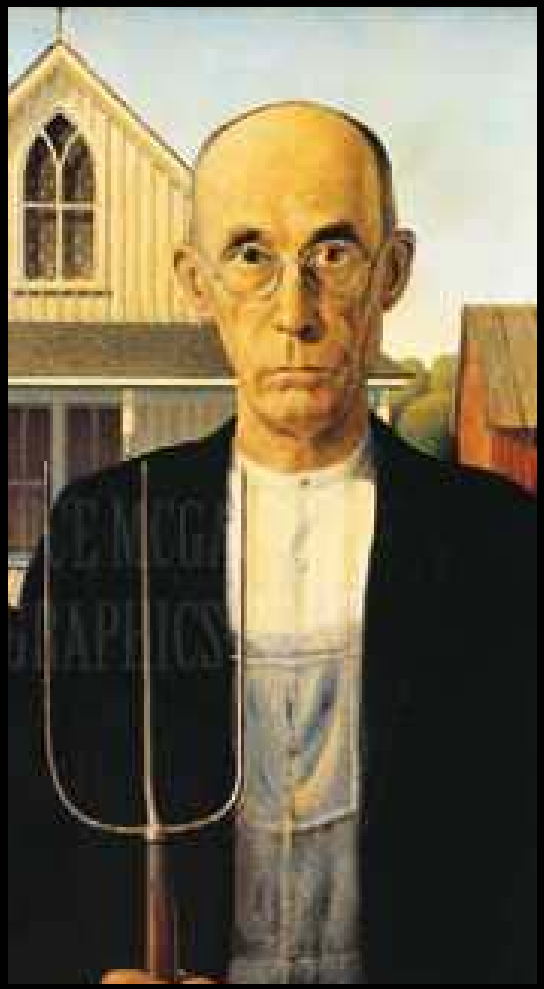


Nothing has energy!


electron volts (billions)
ELECTROWEAK
0
100
200
300
HIGGS METER
OFF
E.W.
GUT

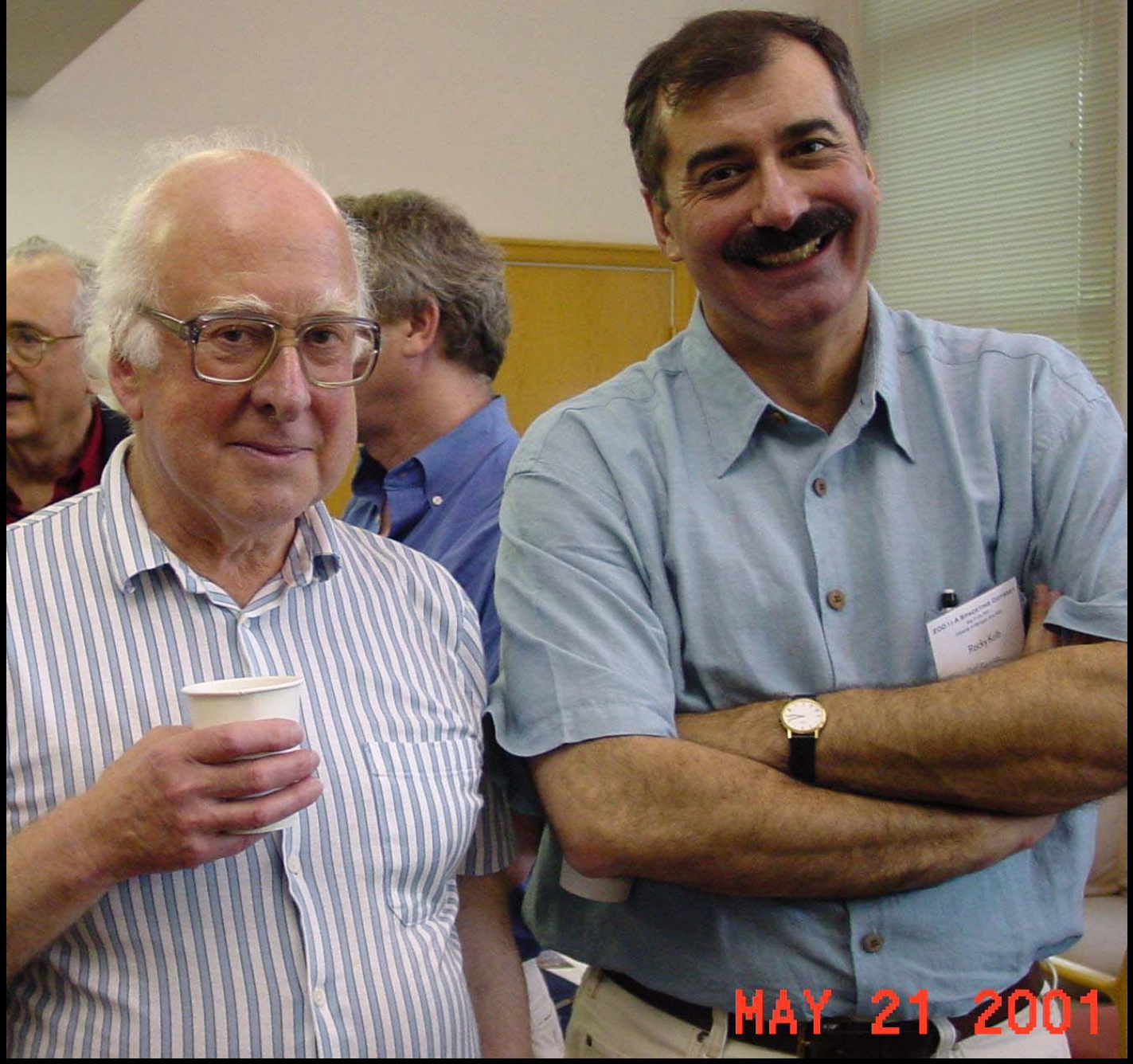
Will Higgs be found in

USA (Fermilab)? **or** **Europe (CERN)?**



Mike Witherell
Director

Luciano Maiani
Director General



Prof. Peter Higgs

Energy of the quantum vacuum

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Quantum field theory: $\rho = \infty$ g cm^{-3}

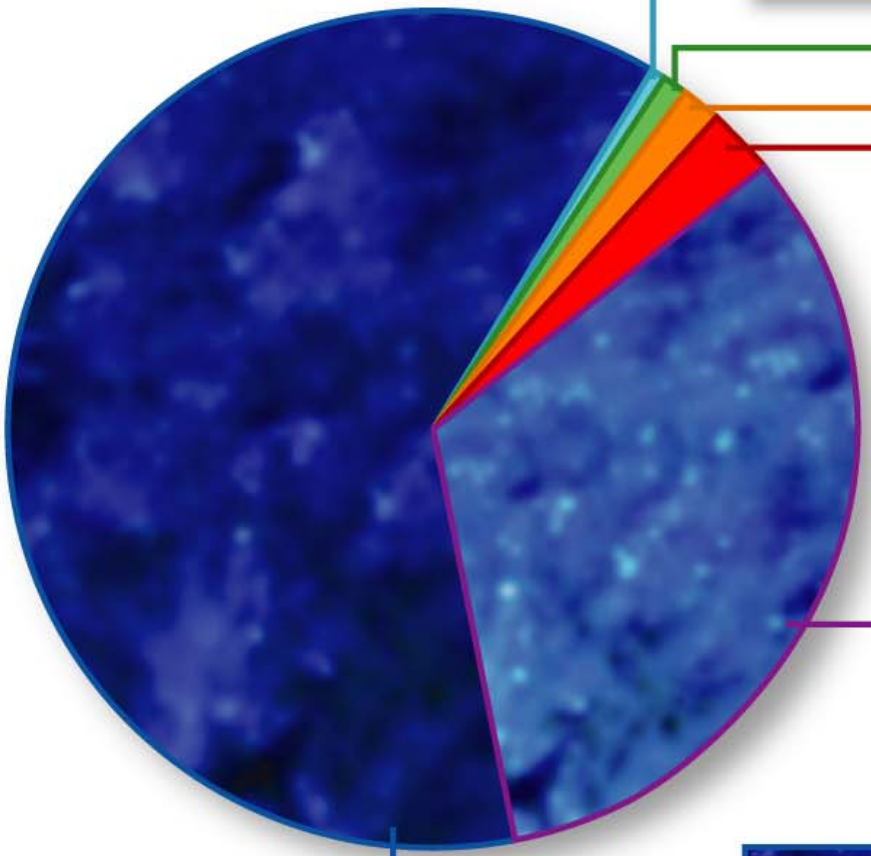
Quantum gravity: $\rho = 10^{+90}$ g cm^{-3}

Supersymmetry: $\rho \leq 10^{+30}$ g cm^{-3}

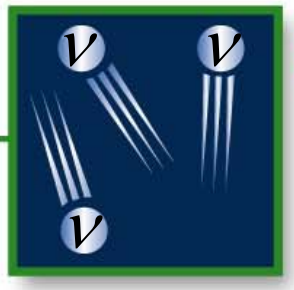
Higgs potential: $\rho \sim -10^{+25}$ g cm^{-3}

Other sources: $\rho \sim \pm 10^{+20}$ g cm^{-3}

Cosmic Pie

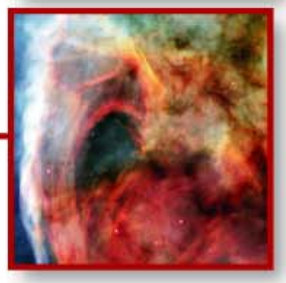


Chemical Elements:
(other than H & He) 0.03%

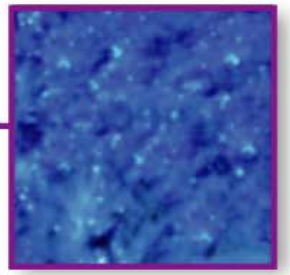


Neutrinos:
0.47%

Stars:
0.5%



Free H
& He:
4%



Dark Matter:
25%

Dark Energy:
70%

Nothing matters!

Every cubic inch of space is a

MIRACLE !

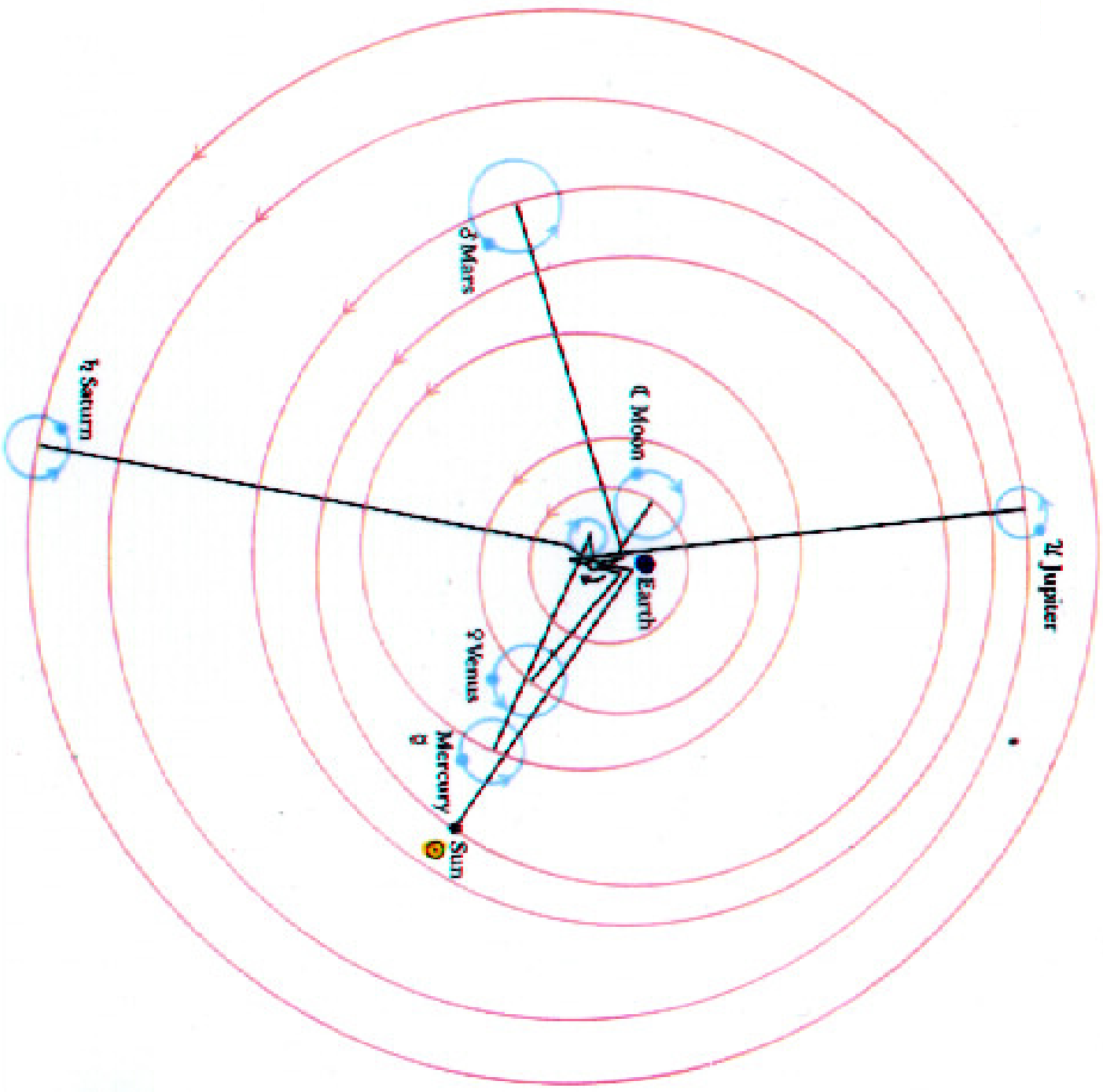
- Walt Whitman

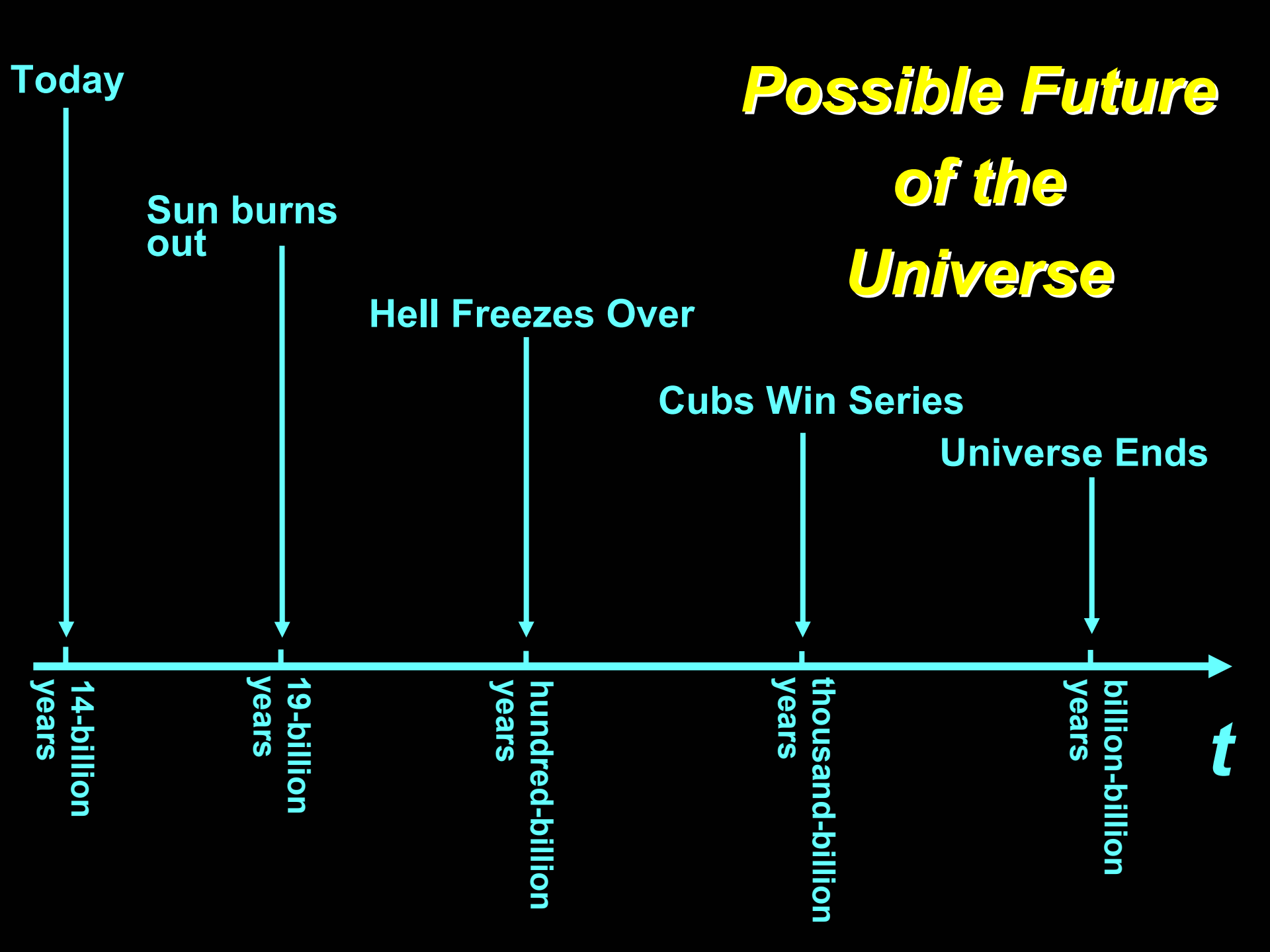
- **background radiation**
- **dark matter**
- **dark energy**
- **virtual particles**
- **Higgs potential**

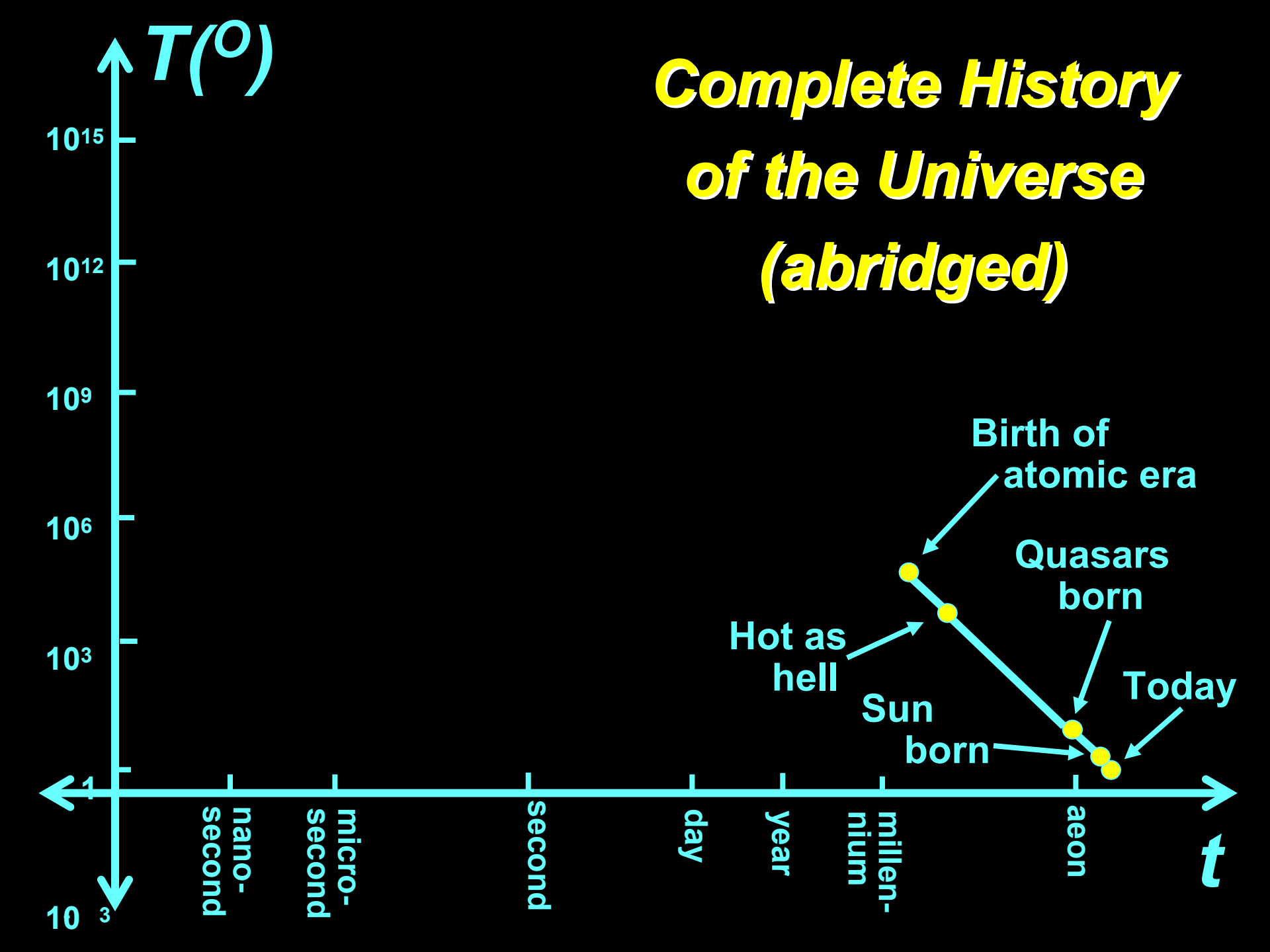
The Cosmic Food Chain

Radiation:	**0.02%**
Heavy elements	**0.03%**
Neutrinos	**0.47%**
Visible matter:	**0.50%**
Dark H & He	**3.98%**
Dark matter:	**25%**
Dark energy:	**70%**

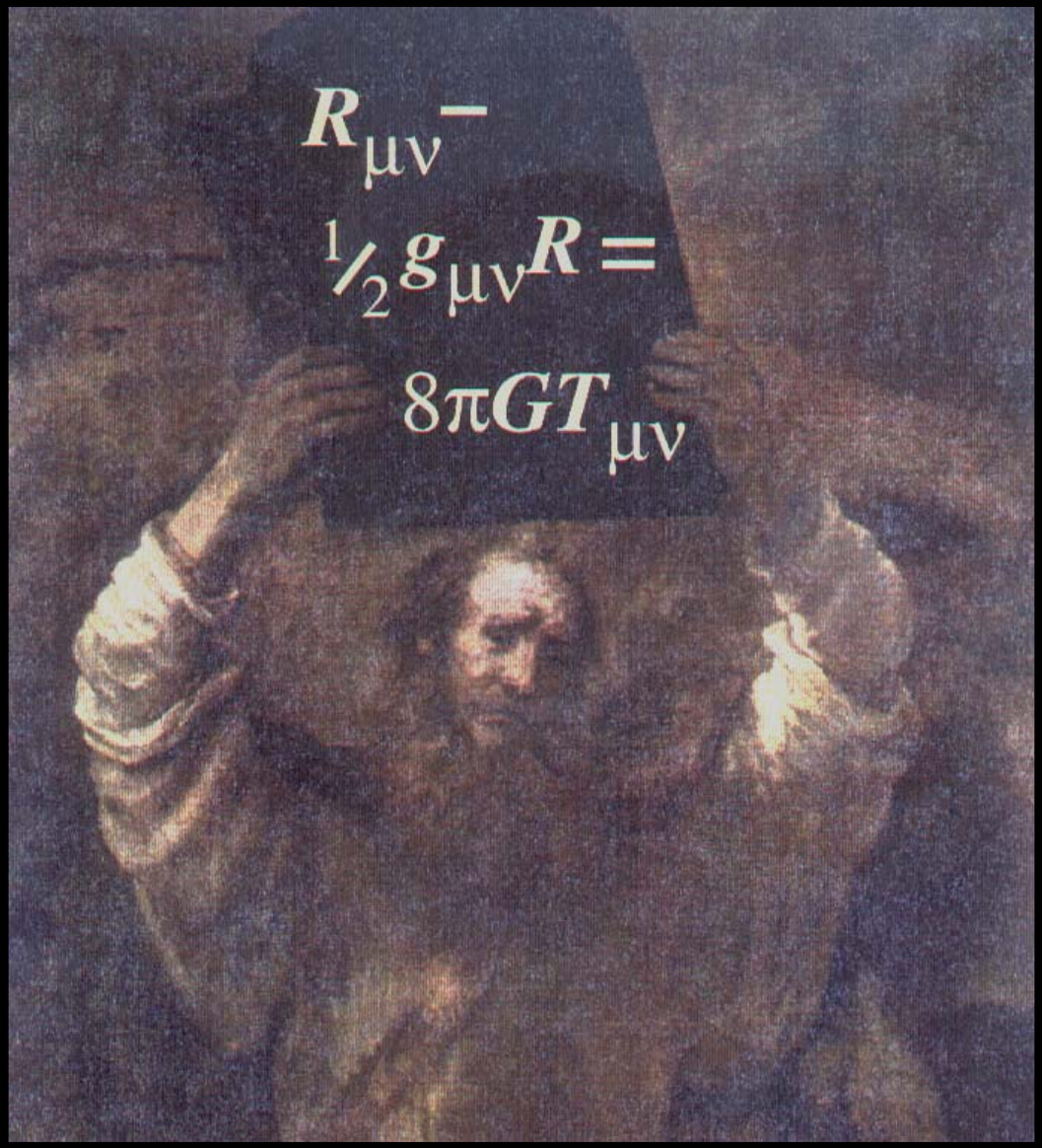
The Ptolemaic System



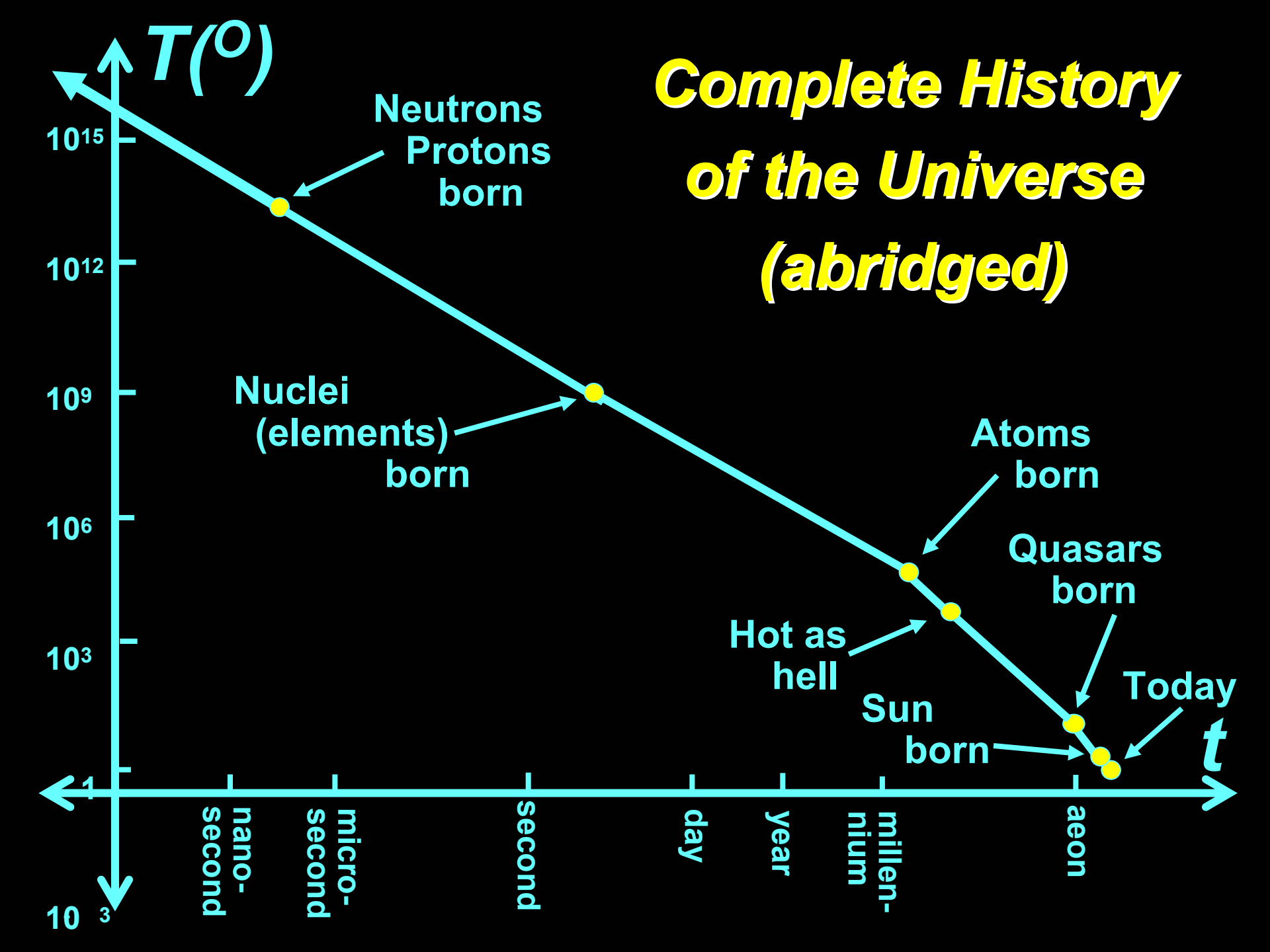

Possible Future of the Universe
Today
Sun burns out
Hell Freezes Over
Cubs Win Series
Universe Ends
14-billion years
19-billion years
hundred-billion years
thousand-billion years
billion-billion years
t


T(°)
Complete History of the Universe (abridged)
10^15
10^12
10^9
10^6
10^3
1
10^-3
Birth of atomic era
Quasars born
Hot as hell
Today
Sun born
nano-second
micro-second
second
day
year
millen-nium
aeon
t

Modern Laws of Genesis



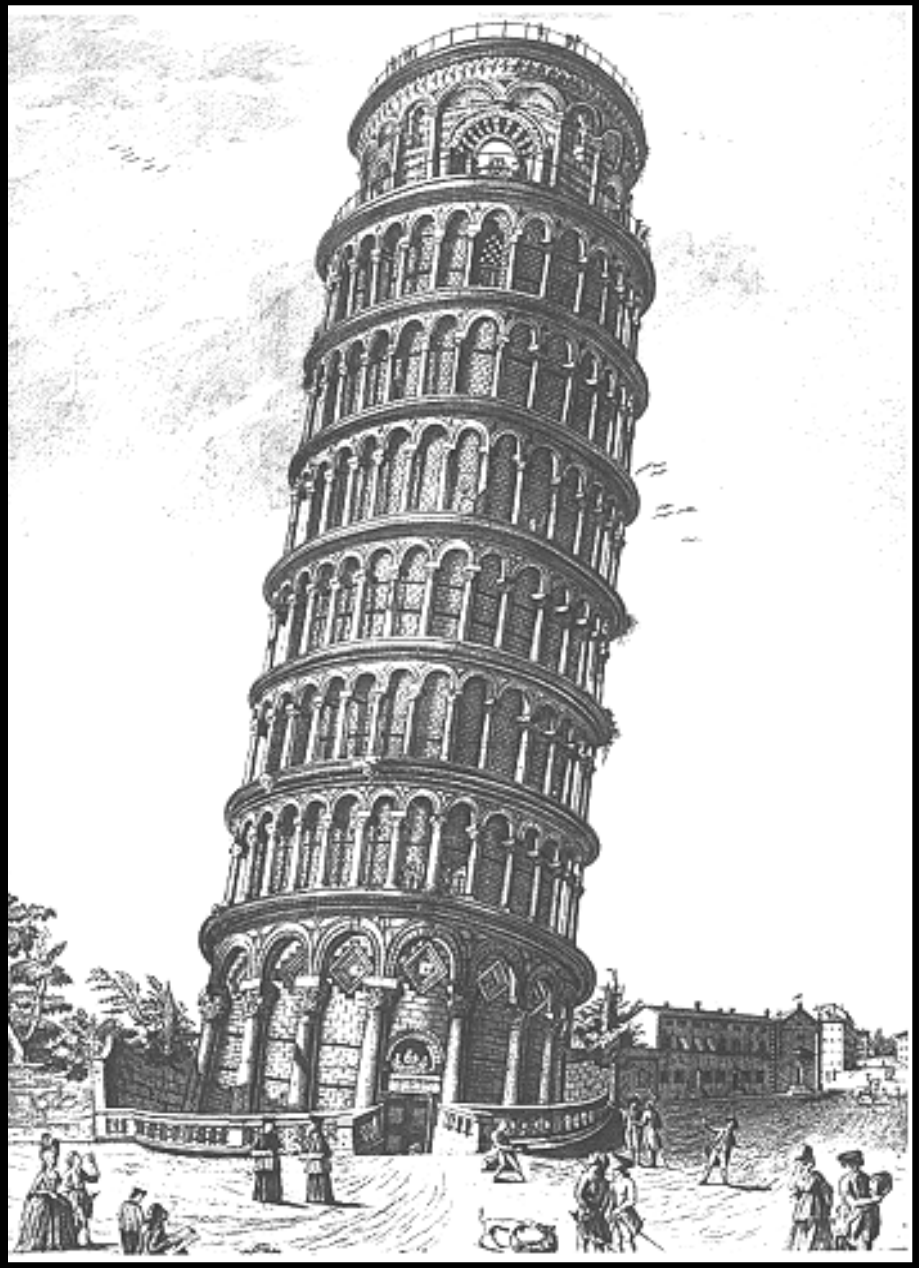
(10 nonlinear partial differential equations)


T(°)
Complete History of the Universe (abridged)
Neutrons Protons born
Nuclei (elements) born
Atoms born
Quasars born
Hot as hell
Sun born
Today
t
10^15
10^12
10^9
10^6
10^3
1
10^-3
nano-second
micro-second
second
day
year
millen-nium
aeon

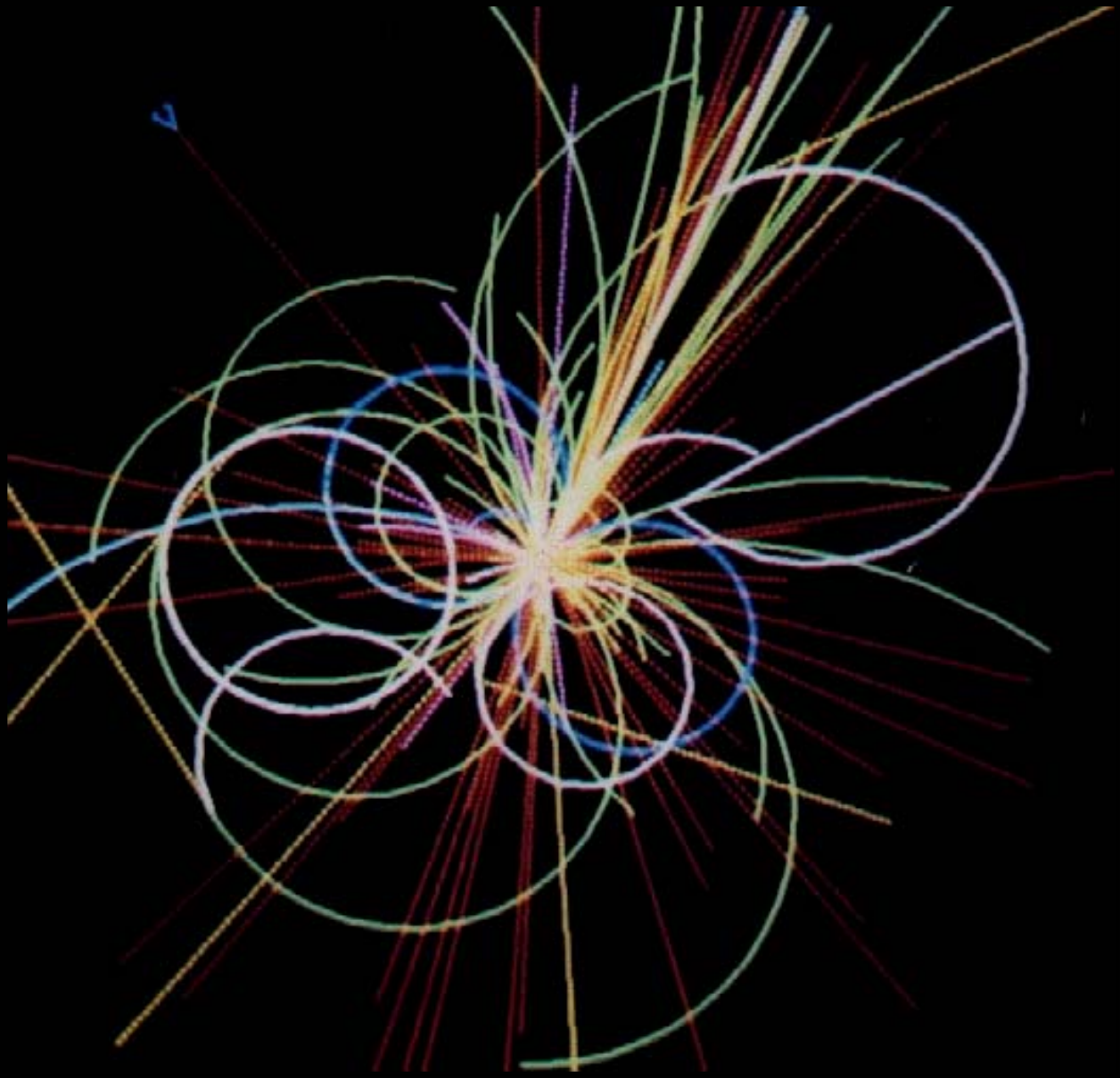
Fermi National Accelerator Laboratory

Particle Accelerator-Telescope-Time Machine

Galileo Pisan Accelerator Laboratory



FERMILAB PRIMORDIAL SOUP




Fermilabs
Primordial
SOUP

Primordial soup

0.000 000 000 004 seconds AB

3,000,000,000,000,000°

CONDENSED

in one can } 50 Earth masses in matter
50 Earth masses in antimatter
\+ extra mountain of matter

HOT

per serving } 10 billion years of total energy output of sun

INGREDIENTS

in every spoonful } every type of elementary particle

Primordial soup

REDIENTS:

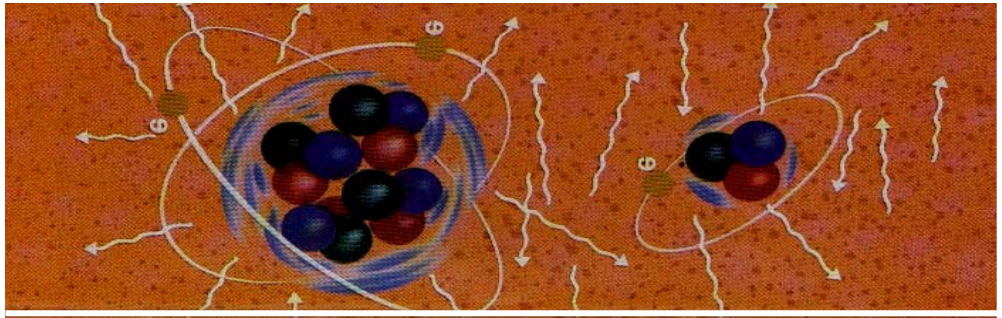
QUARKS
GLUONS (STRONG FORCE)
ELECTRON-LIKE PARTICLES
W's AND Z's (WEAK FORCE)
NEUTRINOS
PHOTONS (ELECTROMAGNETIC
GRAVITONS (GRAVITATIONAL FO
HIGGS BOSONS (???)

GREDIENT:

DARK MATTER

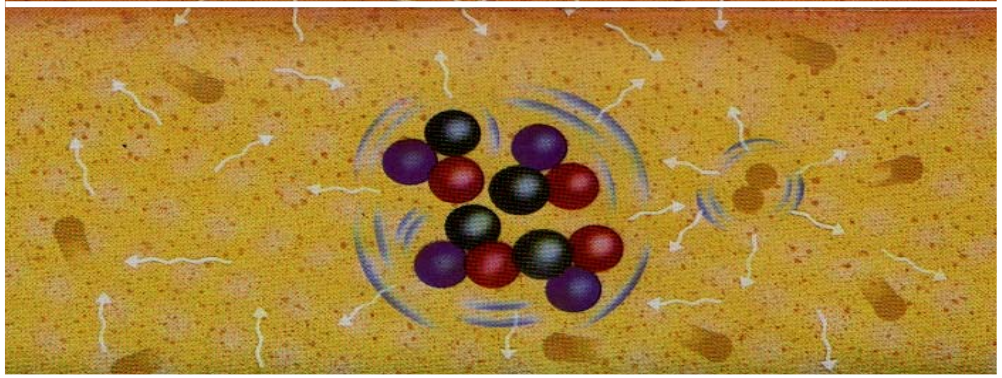
300,000 years

atoms form



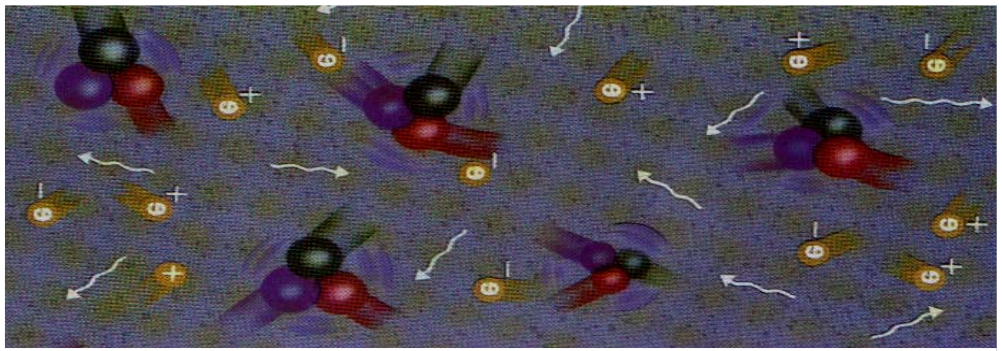
3 minutes

nuclei form



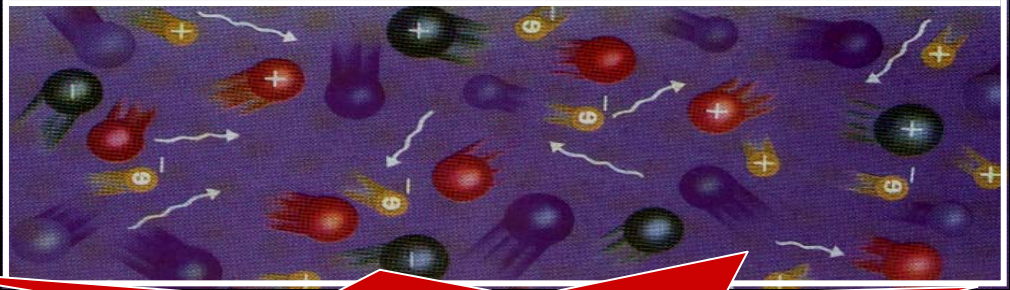
1-micro second

neutrons protons form



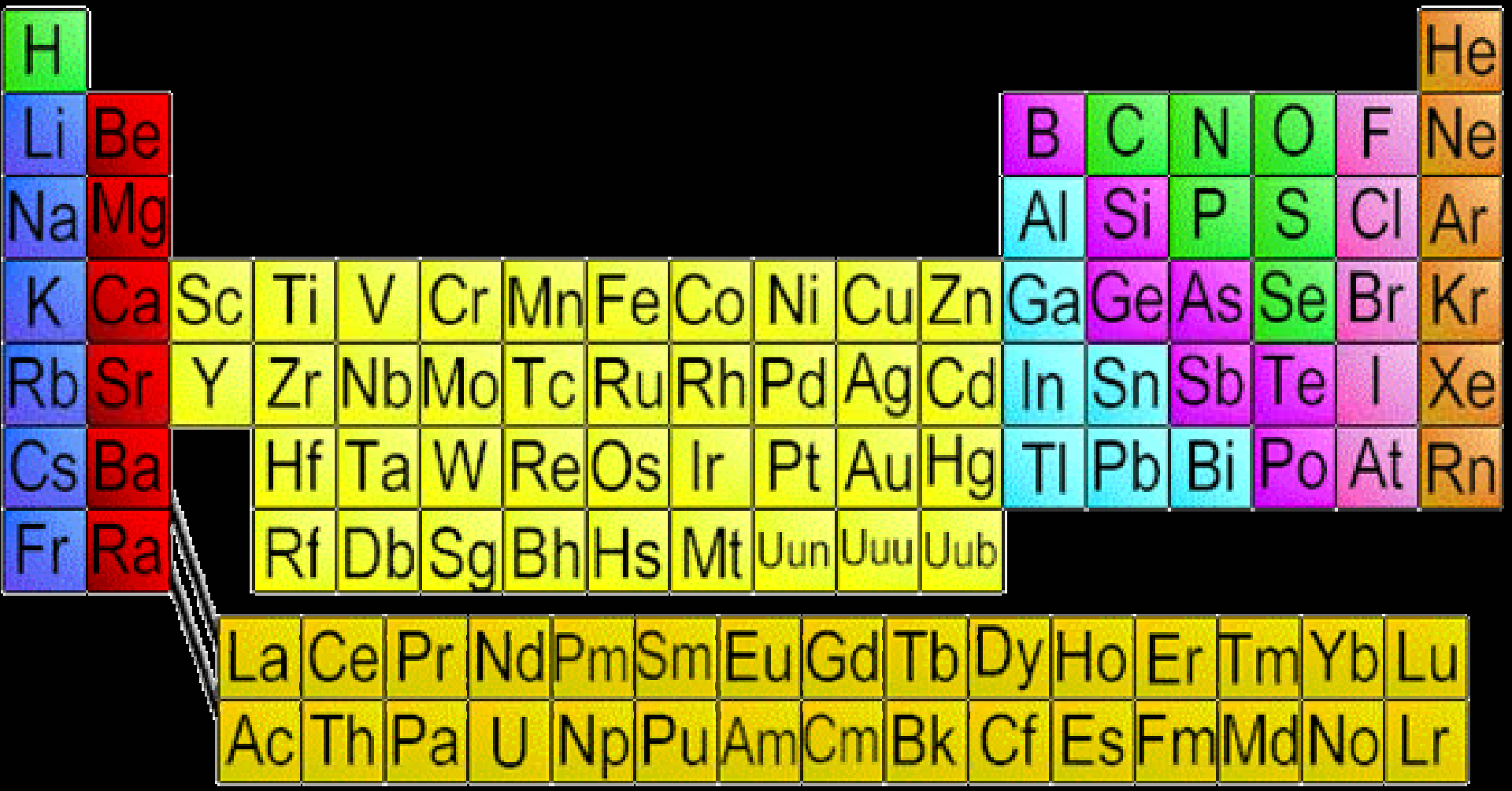
4-pico seconds

primordial soup

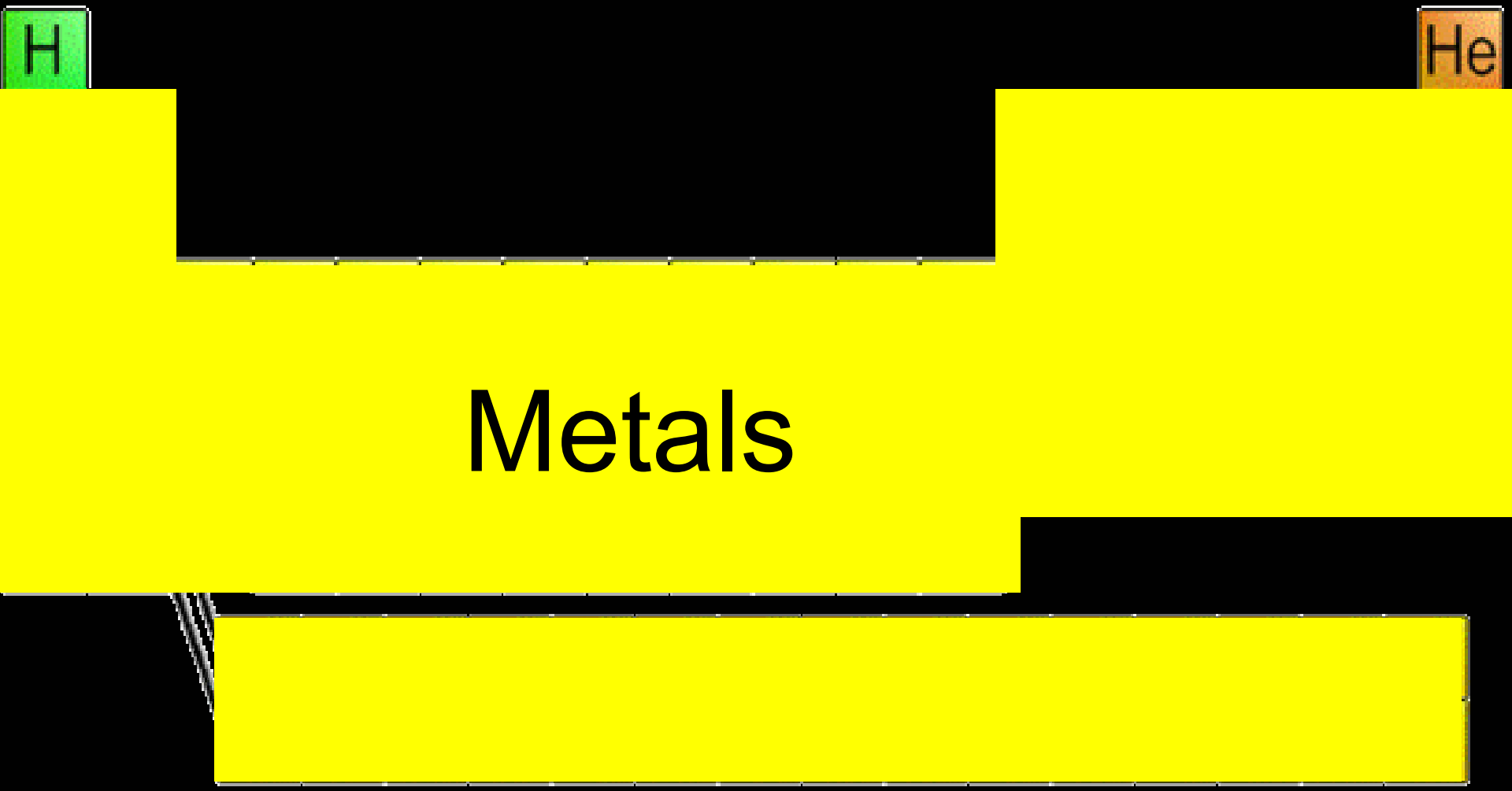


BANG!

Chemist Periodic Table



Cosmologist Periodic Table



The Universe Today:

73% Hydrogen (10^{-5} deuterium)
26% Helium (10^{-5} ^{3}He)
1% Metals

The Universe 3 minutes AB:

76% Hydrogen (10^{-5} deuterium)
24% Helium (10^{-5} ^{3}He)
10^{-8}% Lithium